Introductory Astronomy

Week 8: Cosmology

Clip 8: Precision Cosmology I - CMB

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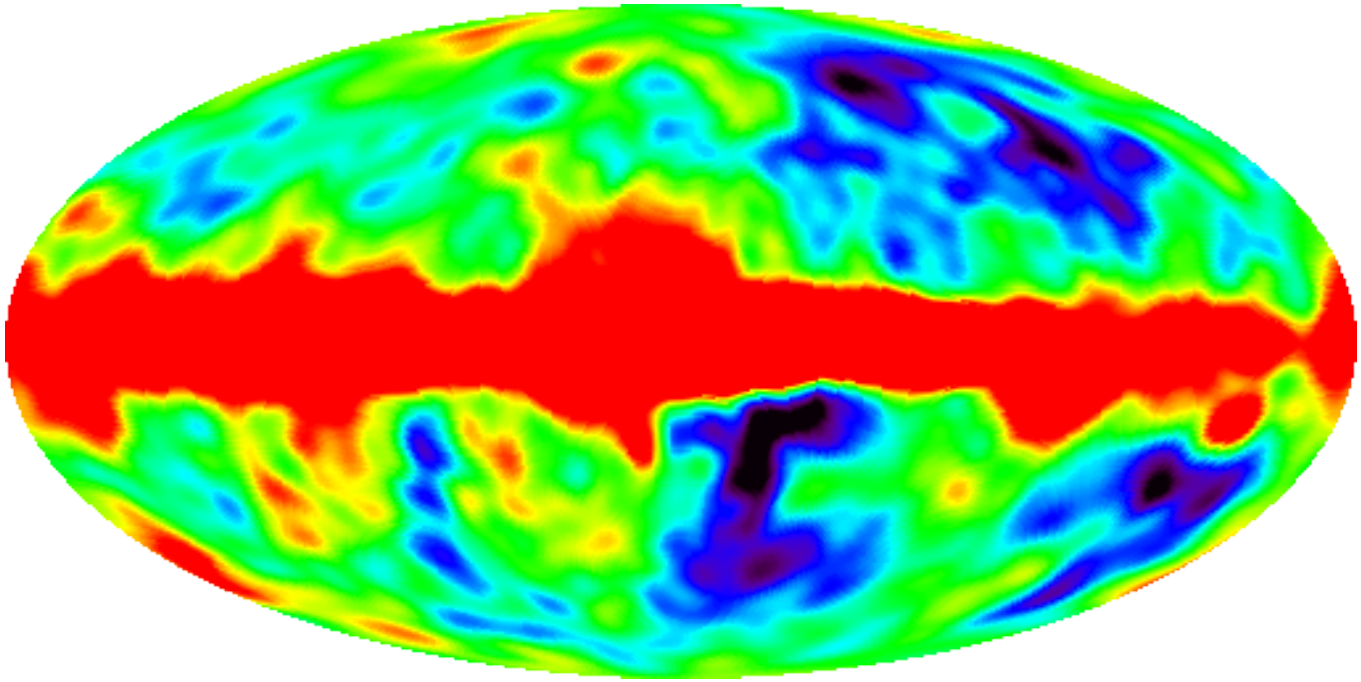
COBE 1992



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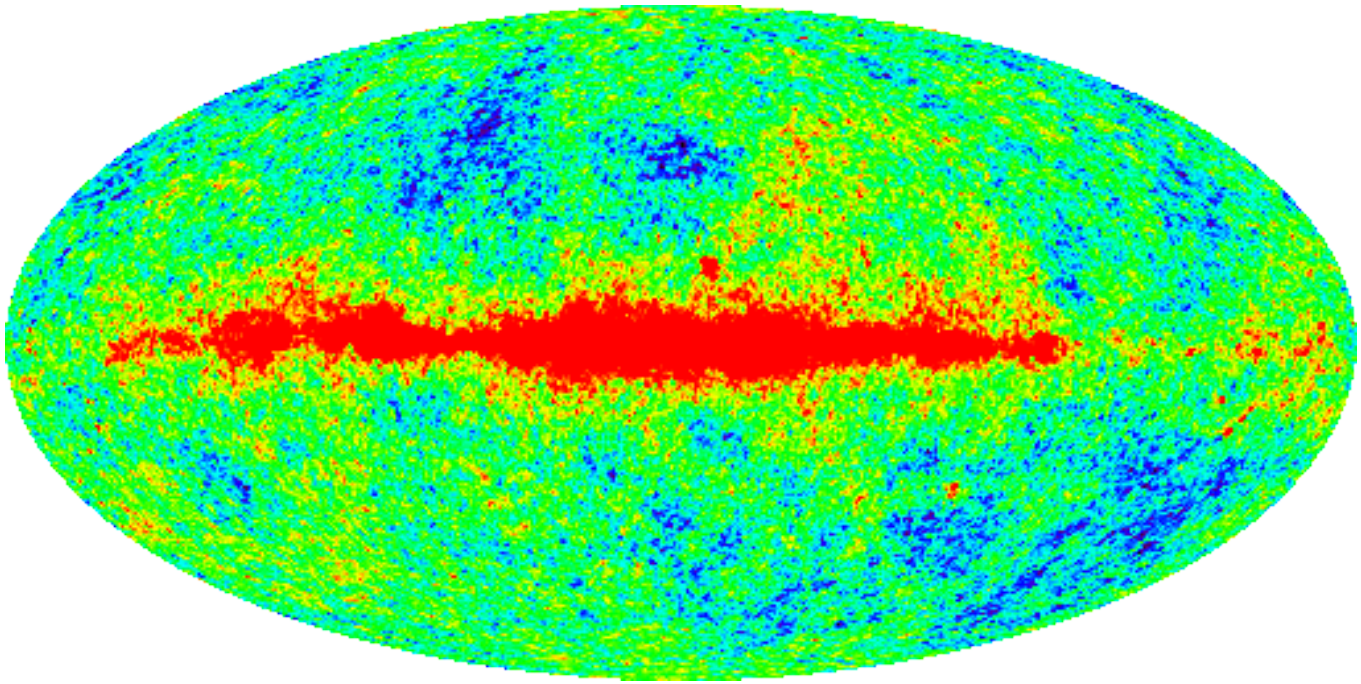
WMAP



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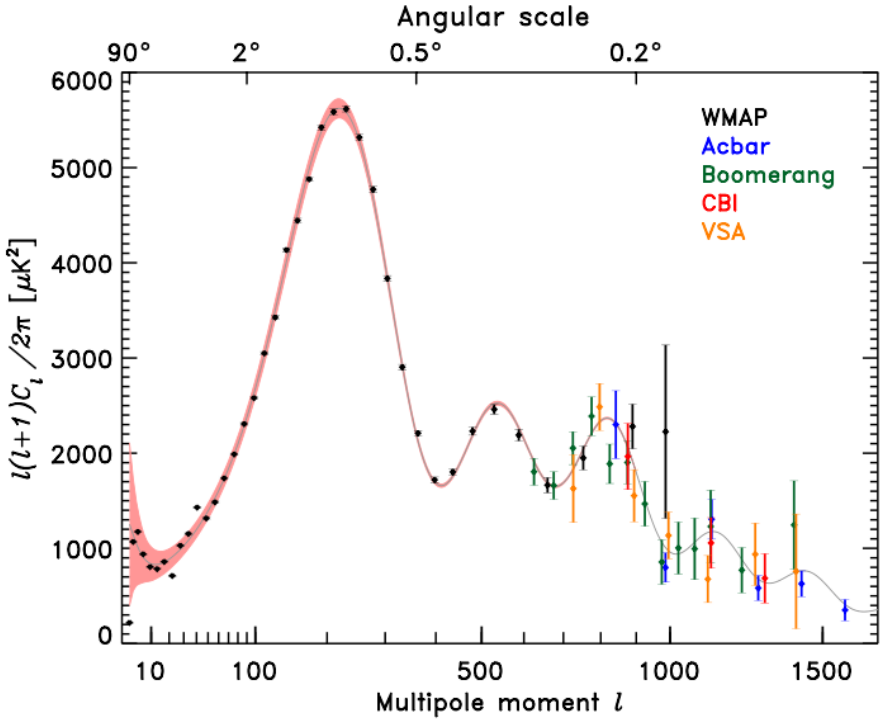
What We Learn

- Analysis of the angular fluctuation spectrum reveals dominant peak at angular size $\theta \sim 1^\circ$
- This is image of density (sound) wave in plasma at $t = 380\,\mathrm{ky}$
- Denser regions are hotter but light is gravitationally redshifted (Sachs-Wolfe)



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Light and Sound

- Denser regions are heated increasing radiation pressure which expands them producing propagating density wave
- Wavelength is of order distance sound can travel in plasma $v_S = c/\sqrt{3}$ by t_{ion}

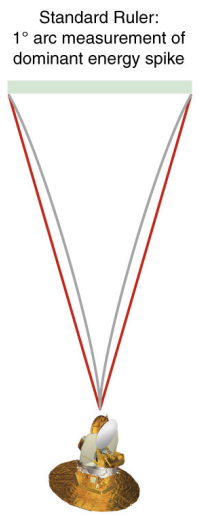
- This is $\lambda = D_h(t_{ion})/\sqrt{3} = \sqrt{3}ct_{ion}$
- We observe this at coordinate distance

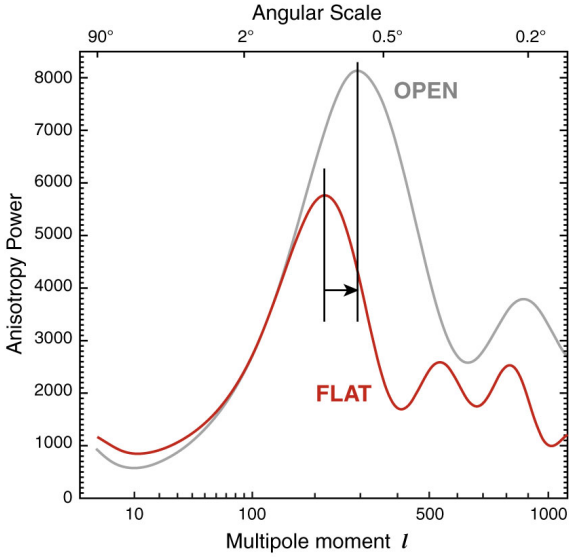
$$\begin{aligned} D &= 3ct_0\left(1-(t_{ion}/t_0)^{1/3}\right) \\ &= 3ct_0\left(1-a_{ion}^{1/2}\right) \end{aligned}$$

Space is Flat

- Use flat universe small angle formula $D_A = D/(1+z)$

$$\begin{aligned}
\theta &= 57.3^\circ \frac{\lambda(1+z)}{D} \\
&= 57.3^\circ \frac{\sqrt{3}\, c\, t_{ion} a_{ion}^{-1}}{3ct_0\left(1 - a_{ion}^{1/2}\right)} \\
&= 57.3^\circ \frac{a_{ion}^{1/2}}{\sqrt{3}\left(1 - a_{ion}^{1/2}\right)} \\
&= 0.97^\circ
\end{aligned}$$





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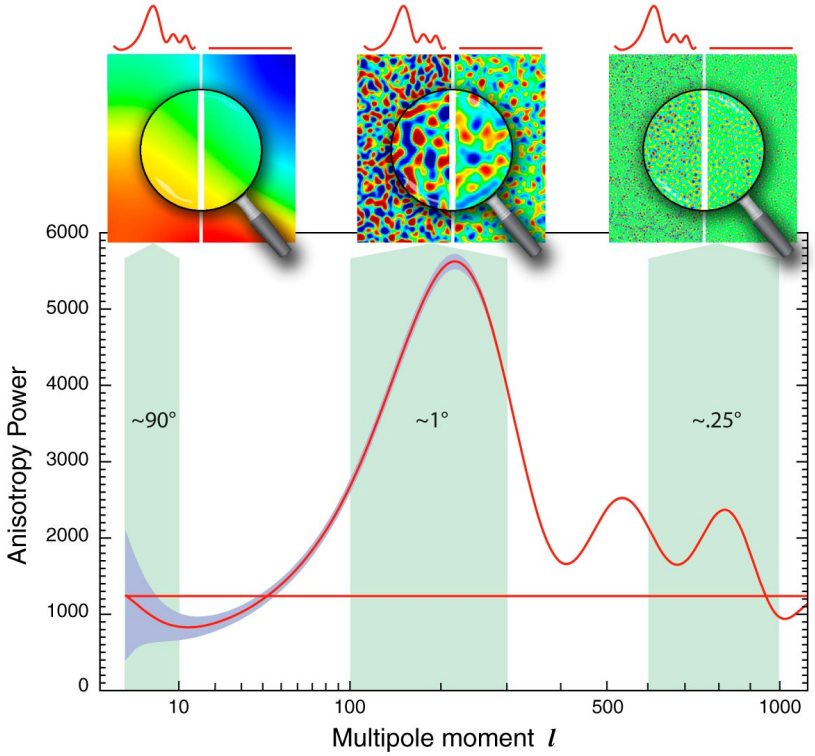
More Structure

- Larger wavelengths are absent because outside particle horizon
- Sound driven by density of dark matter
- Second peak height and position sensitive to Ω_b
- Third peak sensitive to Ω_{DM}



Credits

- CMB Maps and Graphic: NASA/WMAP Science Team
  http://map.gsfc.nasa.gov/universe/bb_cosmo_fluct.html